

Post-Examination Publication No. H07-32806

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CLAIMS

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[Claim(s)]

[Claim 1] energy required for each therapy, and reinforcement -- and -- semi- -- with steady or a proton beam acceleration means to generate the proton beam which has pulse-like time amount structure A transport means to convey said accelerated proton, and a distribution means to distribute said accelerated proton beam in two or more directions, A means to lead the proton beam which was able to be distributed in said two or more directions to a predetermined treatment room, It is fixed and prepared in said treatment room, and the proton beam led to said treatment room is controlled. A dispersion means by which provide the exposure control means which irradiates said proton beam to a predetermined part, and said exposure control means expands said proton beam to a large irradiation field from vertical up down one or a horizontal direction, An energy slowdown means to adjust said proton beam to energy with a range in the living body which is independently established to a dispersion means and agrees in \*\*\*\*\* of said predetermined part, It is the three-dimension-irradiation field means forming which extends the dosage peak width of said proton beam to the width of face which agrees in maximum thickness to said part, and a configuration can be adjusted so that it may be in agreement at the configuration of said part. And the three-dimension-irradiation field means forming possessing the collimator of a couple with which the distance from said part differs, The monitor means for supervising the necessary dosage given to said part of a proton beam, The therapeutic device using the proton beam characterized by generating an exposure stop signal if the monitor value of said monitor means is integrated and the integrated value reaches a preset value, and providing the control means which performs dosage control of said proton beam.

[Claim 2] Equipment according to claim 1 with which said proton beam acceleration means is characterized by having the preliminary acceleration means which carries out preliminary acceleration of a proton, the ion source which carries out negative hydrogen ion generation and said proton, or the negative hydrogen ion, and a main acceleration means to accelerate said proton or hydrogen by which preliminary acceleration was carried out to necessary energy.

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DETAILED DESCRIPTION

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[Detailed Description of the Invention]

(Field of the invention on industry)

This invention relates to the proton beam therapeutic device on which a proton beam is made in agreement with accuracy in for example, a cancer disease blow hole, and large dosage is centralized about the therapeutic device which used the proton beam. It is the system which combined organically the function to make the metal filter to which a proton lineal energy slowdown is simultaneously scattered on, and dosage peak width is expanded especially contribute to dispersion, and to make the irradiation field of a suitable configuration form. (Conventional technique)

The X-ray, the gamma ray, and the electron ray are used for the therapy of the cancer by the radiation, and, recently, the neutron beam has also been introduced into it. These are systems which irradiate the electron ray generated with small electron accelerators, such as a linear accelerator and a betatron, and an X-ray, and have been installed in an a large number hospital. Moreover, although the gamma ray was used, most are the teletherapy equipment which stores a cobalt 60 line source, and a small line source exposure therapeutic device which uses various kinds of radionuclide, and have spread. These radiation therapy systems have the following advantages.

- (a) The therapy of the cancer case which cannot be extracted by operation is possible.
- (b) It is possible to heighten effectiveness by concomitant use with a chemotherapy or a thermotherapy.
- (c) If it succeeds in a therapy, since the deficit and functional disorder of an organization are relief, a patient's social rehabilitation is easy.

(Technical problem which invention tends to solve)

In the conventional radiation therapy system which was mentioned above, if an electron ray is removed, the concept of the attainment range in the inside of the body will not be applied, and it will decrease almost exponentially. Moreover, in an electron ray, since the statistical \*\*\*\* dispersion is large, a range in the living body is not clear.

Therefore, in irradiation field formation of these conventional radiations, formation control of a three-dimension-irradiation field is difficult, and the dosage concentration to the focus is drawing \*\*\*\*\* in approximation by the so-called conformation radiotherapy field method. However, generally, it is complicated and the configuration of a cancer disease blow hole exists in an infinite form and the location where the cancer disease blow hole often approached them in a vital organ. Therefore, with the conventional radiation, there was a fault that it was difficult for the whole cancer disease blow hole to fully give a curative dose, and this caused the recurrence after radiation therapy, without inflicting a failure on normal tissue.

In order for the object of this invention to mitigate the dosage given to normal tissues, such as a circumference organ, as much as possible and to concentrate dosage big enough selectively on an infinite form example, for example, a cancer disease blow hole Expand the proton pencil of lines which made a range of a proton beam in the living body in agreement with cancer focus \*\*\*\*\*, and proton beam dosage peak width was made in agreement with focus thickness, and were converged and conveyed, and \*\*\*\* and the focal dose are indicated for the whole focus by

addition by uniform dosage reinforcement. It is in generating the signal to which an exposure halt is made to carry out with a necessary prescribed dose, automating such control moreover, and offering the therapeutic device using the proton beam which can perform cancer treatment by the proton beam easily.

(The means for solving a technical problem)

the energy which the therapeutic device using the proton beam of this invention needs for each therapy, and reinforcement -- and -- semi- -- with steady or a proton beam acceleration means to generate the proton beam which has pulse-like time amount structure A transport means to convey said accelerated proton, and a distribution means to distribute said accelerated proton beam in two or more directions, A means to lead the proton beam which was able to be distributed in said two or more directions to a predetermined treatment room, It is fixed and prepared in said treatment room, and the proton beam led to said treatment room is controlled. A dispersion means by which provide the exposure control means which irradiates said proton beam to a predetermined part, and said exposure control means expands said proton beam to a large irradiation field from vertical up down one or a horizontal direction, An energy slowdown means to adjust said proton beam to energy with a range in the living body which is independently established to a dispersion means and agrees in \*\*\*\*\* of said predetermined part, It is the three-dimension-irradiation field means forming which extends the dosage peak width of said proton beam to the width of face which agrees in maximum thickness to said part, and a configuration can be adjusted so that it may be in agreement at the configuration of said part. And the three-dimension-irradiation field means forming possessing the collimator of a couple with which the distance from said part differs, It is characterized by providing the monitor means for supervising the necessary dosage given to said part of a proton beam, and the control means which will generate an exposure stop signal if the monitor value of said monitor means is integrated and the integrated value reaches a preset value, and performs dosage control of said proton beam.

By the way, as for said proton beam acceleration means, it is desirable to have the ion source which generates a proton or a negative hydrogen ion, the preliminary acceleration means which carries out preliminary acceleration of said proton or the negative hydrogen ion, and a main acceleration means to accelerate said proton or hydrogen by which preliminary acceleration was carried out to necessary energy.

The equipment of this invention is explained in detail by the following. The equipment of this invention possesses a proton accelerator and a beam transport system. A proton accelerator and a beam transport system consist of control sections of the beam transport systems containing the main accelerator which accelerates a proton to the energy needed for a energy beam transport system and a cancer therapy while leading the proton beam by which preliminary acceleration was carried out with the preceding paragraph acceleration section which performs acceleration for carrying out incidence to the ion source which makes a proton or a negative hydrogen ion generate from a hydrogen molecule, and the injector which performs preliminary acceleration, the injector, and the injector to the main accelerator, and the distribution electromagnet which leads a proton beam to a treatment room, and these devices.

A tandem electrostatic accelerator or a linear accelerator is used for an injector, a negative hydrogen ion is made a tandem electrostatic accelerator, and incidence of a proton or the negative hydrogen ion is made to a linear accelerator.

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MEANS

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(The means for solving a technical problem)

the energy which the therapeutic device using the proton beam of this invention needs for each therapy, and reinforcement -- and -- semi- -- with steady or a proton beam acceleration means to generate the proton beam which has pulse-like time amount structure A transport means to convey said accelerated proton, and a distribution means to distribute said accelerated proton beam in two or more directions, A means to lead the proton beam which was able to be distributed in said two or more directions to a predetermined treatment room, It is fixed and prepared in said treatment room, and the proton beam led to said treatment room is controlled. A dispersion means by which provide the exposure control means which irradiates said proton beam to a predetermined part, and said exposure control means expands said proton beam to a large irradiation field from vertical up down one or a horizontal direction, An energy slowdown means to adjust said proton beam to energy with a range in the living body which is independently established to a dispersion means and agrees in \*\*\*\*\* of said predetermined part, It is the three-dimension-irradiation field means forming which extends the dosage peak width of said proton beam to the width of face which agrees in maximum thickness to said part, and a configuration can be adjusted so that it may be in agreement at the configuration of said part. And the three-dimension-irradiation field means forming possessing the collimator of a couple with which the distance from said part differs, It is characterized by providing the monitor means for supervising the necessary dosage given to said part of a proton beam, and the control means which will generate an exposure stop signal if the monitor value of said monitor means is integrated and the integrated value reaches a preset value, and performs dosage control of said proton beam.

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A tandem electrostatic accelerator or a linear accelerator is used for an injector, a negative hydrogen ion is made a tandem electrostatic accelerator, and incidence of a proton or the negative hydrogen ion is made to a linear accelerator. The linear accelerator which the linear accelerator which carries out incidence of a tandem electrostatic accelerator and the proton

carries out preliminary acceleration of the proton, carries out incidence to the main accelerator, and carries out incidence of the negative hydrogen ion carries out preliminary acceleration of the negative hydrogen ion, and it carries out incidence to the main accelerator with an electrification conversion method.

The main accelerator is a synchrotron, and after it performs high frequency acceleration from the energy of preliminary acceleration of the proton by which incidence was carried out to the energy corresponding to the location and configuration of the focus, it picks out a proton from the main accelerator to a beam transport system.

About the ejection of a proton beam, the inside of the time amount using resonance can choose the late ejection which takes out a beam in semi-stationary, or the quick ejection taken out in the time amount to which a proton goes around the main accelerator, and is led to an exposure control unit the horizontal direction of 1 or 2 or more treatment rooms, or vertical up down [ either ] by a distribution electromagnet and a beam transport system also with the same proton beam taken out by which approach.

The signal from an exposure control device performs acceleration of the proton by the accelerator, and the interlock system and computer of security perform control of an accelerator and a beam transport system.

The theoretic configuration of an exposure control unit consists of the three-dimension-irradiation field formation section and the dosage Monitoring Department.

The three-dimension-irradiation field formation section has an energy slowdown machine, the heavy-metal plate formed in the energy slowdown machine upper part, and a dosage peak width amplification filter.

An energy slowdown machine changes the thickness of the part which the wedge-shaped energy-absorbing matter of two sheets overlaps, and makes necessary energy-absorbing perform. And it is remotely controllable in thickness necessary with the precision of 1mm \*\*\*\*\* within 1 minute.

The optical exposure mirror upper part is equipped with the primary scattering object of a heavy-metal plate for amplification of a convergence beam, and a dispersion function is strengthened with the ring stopper of the lower part.

A dosage peak width amplification filter carries out sequential change of the sharp dosage peak section energy which is a energy-absorbing metal body with dip, and carries out incidence to thickness, and is cumulatively made into a dosage peak with necessary flat width of face. 15 sets is prepared at 1cm step to 15cm, the movable carriage which has 16 frames in the rectangle of 4x4 is equipped with this, and it is remotely chosen from amplification width of face of 1cm. In addition, among those, one frame is made into a blank and enables the exposure by the dosage peak of a basis.

The dosage Monitoring Department has a monitor ionization chamber with the transparency form parallel plate electrode of the Lord and a subcouple, the amplifier of the output current, an addition drop, and a dosage presetting machine. The dosage Monitoring Department will generate an exposure stop signal, if an integrated value reaches a prescribed dose, and it stops a proton beam exposure, and a computer is made to perform actuation and control.

(Work for )

According to the therapeutic device using the proton beam by this invention constituted as mentioned above, a proton is accelerated and a patient's focus part can be irradiated. A proton beam can acquire the dose distribution which energy does not decrease exponentially like the conventional X-ray and a gamma ray even if it carries out incidence to the inside of the body, but has a dosage peak in the predetermined depth. Moreover, the dose distribution can be adjusted easily and range adjustment of a proton beam can be performed.

therefore, cancer -- like -- an infinite form -- and -- double -- even if it is a \*\*\*\* configuration, a predetermined part can be irradiated by adjusting the dose distribution of a proton beam. Therefore, a normal organization can be treated, without doing a failure.

Moreover, according to the concrete configuration of the exposure control means of this invention, the exposure control means is installed fixed to vertical above, vertical down, and a horizontal direction in a treatment room. If it does in this way, adjustment of the various

members for changing the dose distribution of a proton beam becomes easy, and a safe and suitable therapy can be realized for this ease.

Thus, according to the exposure control means of this invention, the dosage given to normal tissues, such as a circumference organ, is as much as possible mitigable. moreover, the proton pencil of lines which made a range of a proton beam in the living body in agreement with cancer focus \*\*\*\*\*, and proton beam dosage peak width was made in agreement with focus thickness, and were converged and conveyed in order to concentrate selectively the dosage big enough which is an infinite form, for example on a cancer disease blow hole -- expanding -- the focus whole -- uniform dosage reinforcement -- \*\*\*\* -- things become possible. Furthermore, the focal dose is indicated by addition, and since the signal to which an exposure halt is made to carry out with a necessary prescribed dose is generated, cancer treatment by the proton beam can be performed easily. And such control is automatable.

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EXAMPLE

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(Example)

With reference to a drawing, one example of the proton beam irradiation equipment of this invention is explained below.

The configuration of a proton accelerator 10, the beam transport system 12, and the inside energy beam transport system 16 is shown in drawing 1 and drawing 2. Drawing 2 is drawing seen from [ of the beam transport system 12 of drawing 1 ] II-II. A proton accelerator 10 consists of a synchrotron of six square shapes, and has the RF acceleration section 14. If a synchrotron is made into six square shapes, when the design of the strong focusing mold of high performance becomes easy, for example compared with the thing of four square shapes and a bay increases, the ejection of various beams will become possible. The beam transport system 12 possesses the vertical above beam transport system 18, the vertical down beam transport system 20, and the horizontal beam transport system 28.

In order to treat by making a proton reach the focus of the depths, the proton of necessary beam reinforcement must be accelerated to necessary energy. For example, in order to make a proton reach a depth of 32cm in the living body, the energy of 230MeV is needed. The procedure in this example which accelerates a proton to such energy is explained below.

The negative hydrogen ion which was made to generate a negative hydrogen ion and was first generated from the ion source of a hydrogen molecule is accelerated to 50keV(s) electrostatic, and in order to perform preliminary acceleration, incidence is carried out to an injector 22. The terminal voltage tandem electrostatic accelerator of 2.5MV is used as an injector 22. When a tandem electrostatic accelerator is used, there is MEITTO which can reduce energy width of face. It is accelerated to 2.5MeV(s), and a negative hydrogen ion is changed into a proton by the carbon thin film, and is accelerated to 5MeV in a terminal. A proton is led to a proton accelerator (the main accelerator) 10 by the inside energy beam transport system 16.

The main accelerator 10 is the strong focusing mold synchrotron of the super-period 6, and shows the key parameter in the 1st table. It goes around on the orbit of about 35m of round, whenever it passes the RF acceleration section, it is accelerated, and a proton reaches 230MeV (s) after about 0.5 seconds. The proton which reached necessary energy is picked out from a synchrotron 10, and is led to a treatment room by the beam transport system 12.

If the energy of a proton beam is not a thing corresponding to the depth of the focus, it will not become. In a synchrotron 10, although the ejection in the energy of arbitration is possible in the middle of acceleration, let energy of a proton beam be the three-stage of 120MeV(s), 180MeV, and 230MeV in consideration of the soundness and quick nature of a change of energy as a first stage story. After this is attained, ejection in the energy of arbitration is performed.

Although it generally became certain with the synchrotron 10 to attain design energy with the current technique, it needs to be adjusted careful after the \*\*\*\*\* consideration in a design stage, and completion to attain 20nanoampere (nA) which is the target of beam reinforcement. Many of beam loss takes place in the time of the acceleration initiation in a synchrotron 10, and the case of the ejection of the proton from a synchrotron 10 at the time of the incidence to a synchrotron 10. Since the beam reinforcement of an injector 22 is not so high, many times incidence of the proton of a synchrotron 10 is performed, and the beam reinforcement of a



synchrotron 10 is secured.

In addition, if the linear accelerator of 8 or more MeVs which carries out incidence of the negative hydrogen ion is used as an injector 22, using conversion to the proton of the negative hydrogen ion by the carbon thin film, it will be efficient and proton incidence to the easy synchrotron 10 of beam control on the strength will be made.

The beam loss at the time of acceleration initiation prepares an orbital correcting magnet beforehand, and corresponds by adjustment of the synchrotron 10 including these. The beam loss in the ejection from a synchrotron 10 brings about the increment in residual radioactivity, and requires caution most.

The method of beam ejection can choose the late ejection by half-integer resonance with high ejection effectiveness, or the quick ejection by the quick kicker who stands up. Therefore, the irradiation field formation by beam scan also becomes possible by late ejection.

or [ that quick beam ejection effectiveness starts proton acceleration synchronizing with motion of a focus organ while 100% becomes possible theoretically and it enables measurement of the attainment location of the proton beam in the inside of the body by the supersonic wave ] -- or the exposure which reduced the dose of radioactivity of normal tissue is attained by accumulating the proton beam accelerated beforehand in a synchrotron 10, and taking out a proton beam synchronizing with motion of a focus organ.

The signal from the monitor ionization chamber (reference mark 86 of drawing 3 ) formed in the exposure control unit performs acceleration of the proton beam by the accelerator. The proton beam by late ejection and the proton beam by quick ejection are taken out by the same beam transport system 12. A proton beam is supplied to the vertical up down beam transport systems 18 and 20, the horizontal beam transport system 28, and other 2nd treatment room 26 from the vertical up down beam transport systems 18 and 20 among two treatment rooms in the 1st treatment room 24. Vertical up down one and horizontal selection are based on the distribution electromagnet 30.

In the beam transport system 12, the power source of electromagnets (for example, electromagnet shown by the reference marks 62 and 64 of drawing 1 ) other than the electromagnet (for example, 90-degree deflection electromagnet of drawing 3 ) required for leading a proton beam to a necessary exposure control device is made into \*\* for the object of security. The conditions of this procedure are included in the interlock system stored in the operation control board (not shown) of all systems with other general conditions. The computer formed in said operation control board performs setting out of the service condition of an accelerator 10 and the beam transport system 12.

The concrete detail configuration of the exposure control unit 34 is shown in drawing 3 . the exposure control unit 34 of a graphic display -- the first treatment room 24 -- the upper and lower sides -- when 3 sets of vertical and horizontal exposure control units were installed and the beam from the vertical above beam transport system 18 was controlled, the detailed configuration about vertical equipment was shown. It becomes the configuration same about other 2 sets which controls the beam of the vertical down beam transport system 20, the beam of the horizontal beam transport system 28, and the beam of the horizontal beam transport system 28. Other 2 sets are shown by reference marks 70 and 72.

A patient 38 is fixed on the central dental chair 36 so that the focus may be made in agreement with the medial axis of each exposure control unit. The check of the location is performed by moving X-ray tube 39 and an image intensifier (I.I.) 40 on the same axle.

Irradiation field formation of a proton beam scans a thin bundle proton beam with the electromagnet 42 for a scan, and expands it with the primary scattering object 44, and is made by forming distribution of homogeneity reinforcement of 20x20cm or more in an exposure location mostly with the ring stopper 46. The check of the breadth of the beam of the irradiation field formation on the front face of a patient is made by the light field mirror 80.

Range adjustment of beam shaft orientations decreases the energy corresponding to a necessary range in the living body with an energy fine adjustment unit 48, it chooses a ridge filter 50 so that dosage peak width may agree in focus thickness, and it expands the width of face. Moreover, bolus 82 is formed, in order to make it correspond to a patient body surface and the

configuration of the focus, and the depth of the non-<sup>\*\*</sup> value focus in the living body and to perform energy adjustment of a proton beam. The thickness of bolus 82 is changing with each locations, and absorbs the energy of a proton beam by passing a proton beam through each of that location.

The configuration of the block collimator 52 and the configuration of the last collimator 54 are adjusted so that it may be in agreement with a focus configuration.

The monitor ionization chamber 90 is formed between the ridge filter 50 and the energy fine adjustment unit 48. If this monitor ionization chamber 90 functions as some dosage Monitoring Department and the integrated value of the amount corresponding to that output current exceeds the preset value corresponding to a prescribed dose, an exposure stop signal will be generated and a proton beam exposure will be suspended. These control is made by the computer (not shown).

~~In addition, the shutter device 84 and the electric shielding block 86 are established for the security of the treatment room which does not irradiate a proton beam.~~

Moreover, the arrangement condition of each above-mentioned element prepared in this irradiation equipment, conditions, etc. are adjusted according to a patient's 38 condition.

Although this adjustment is possible also by hand control, it is more desirable for a computer to adjust automatically based on a patient's data.

Since a vertical perpendicular and 3 sets of level exposure control units are being fixed, actuation is easy, and while being able to perform a positive therapy, a maintenance is easy according to such irradiation equipment.

Moreover, since each element of the electromagnet 42 for a scan, the primary scattering object 44, and ring stopper 46 grade is included in irradiation equipment almost fixed, adjustment is easy and a therapy with it is attained. [ the high therefore safety of equipment and ] [ exact ]

The example to which range expanded the proton beam dose distribution which has a sharp peak, and the width of face of the sharp dosage peak to about 25cm of underwater, and drawing 4 adjusted range is shown. It was almost fixed when removing the case where the configuration of an amplification dosage peak and the dosage reinforcement of an axis of ordinate decreased energy extremely also by such range adjustment.

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DESCRIPTION OF DRAWINGS

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[Brief Description of the Drawings]

Drawing 1 is a top view of the therapeutic device using the proton beam concerning this invention,

Drawing 2 is drawing seen from the II-II line of a down-stream beam transport system from the distribution electromagnet among the equipment of drawing 1 ,

Drawing 3 is a block diagram of the vertical upper part part of the exposure control unit used for the therapeutic device of this invention,

Drawing 4 is drawing showing the amount distribution of phase twisted pair lines underwater [ with the proton beam to which the acceleration proton beam which shows a sharp dosage peak to about 25cm of underwater / which was irradiated by this equipment /, and each range slowed down, and dosage peak width was expanded ].

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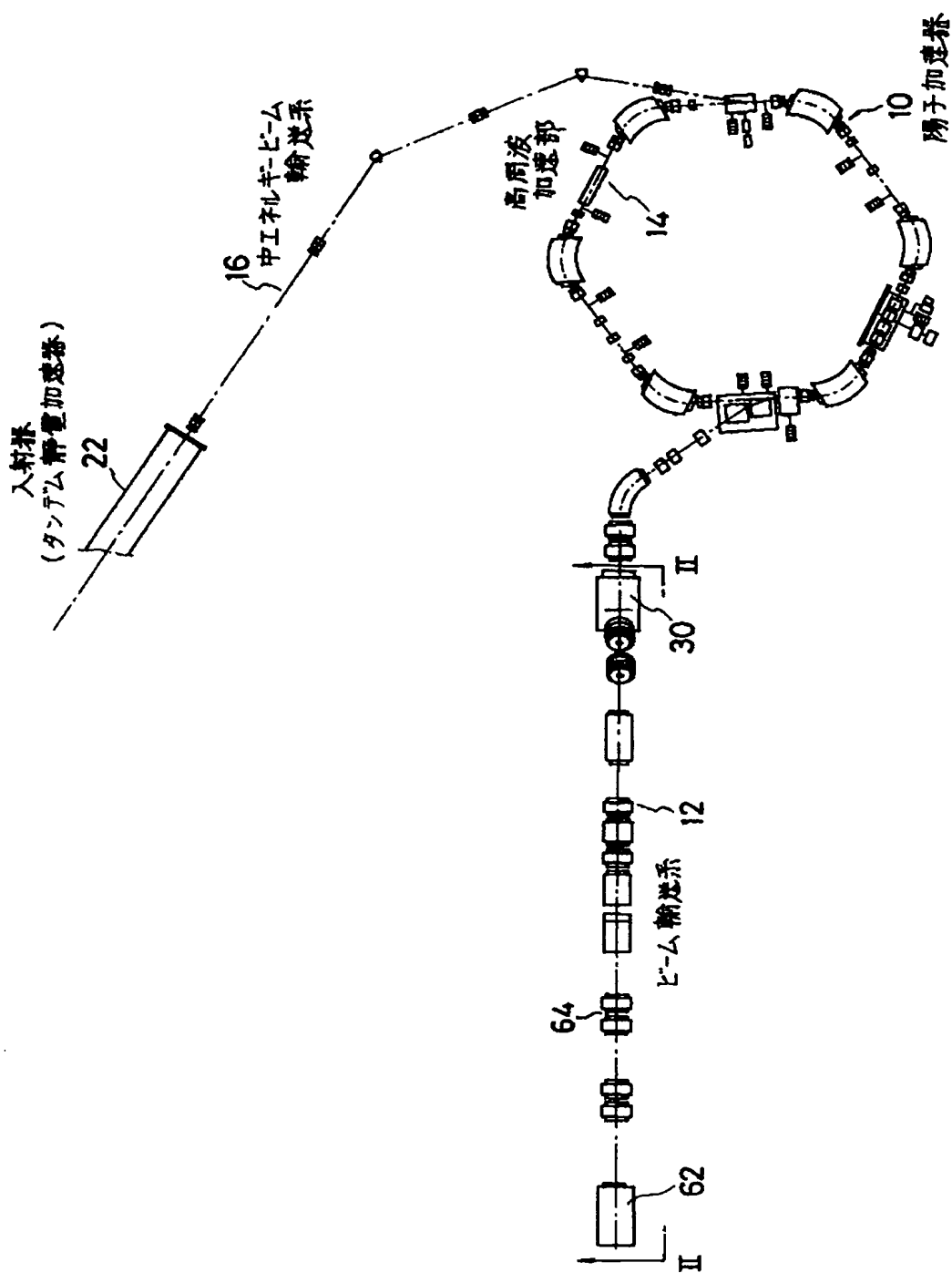
3.In the drawings, any words are not translated.

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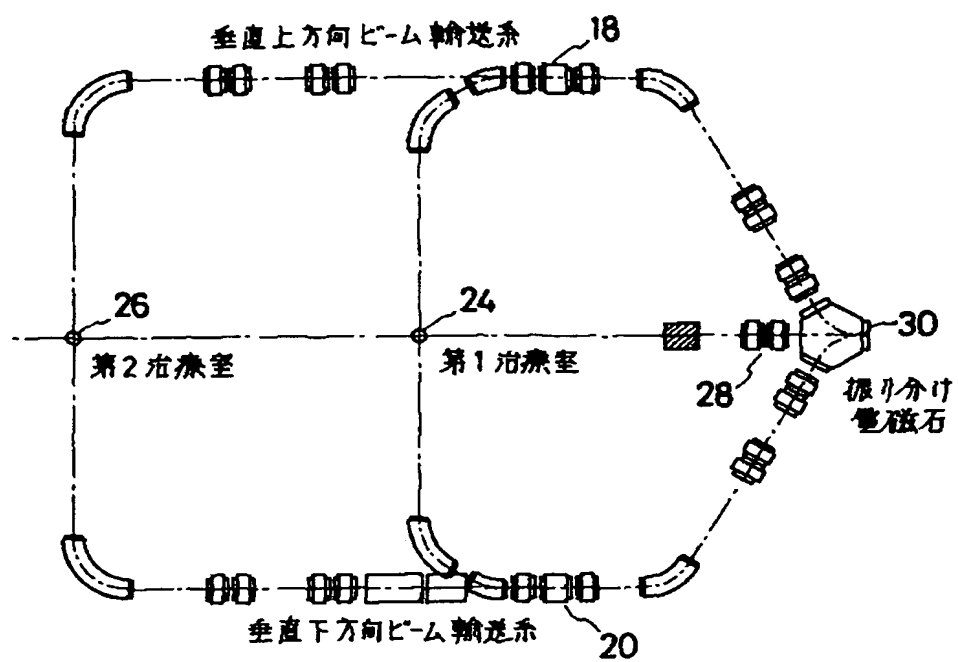
DRAWINGS

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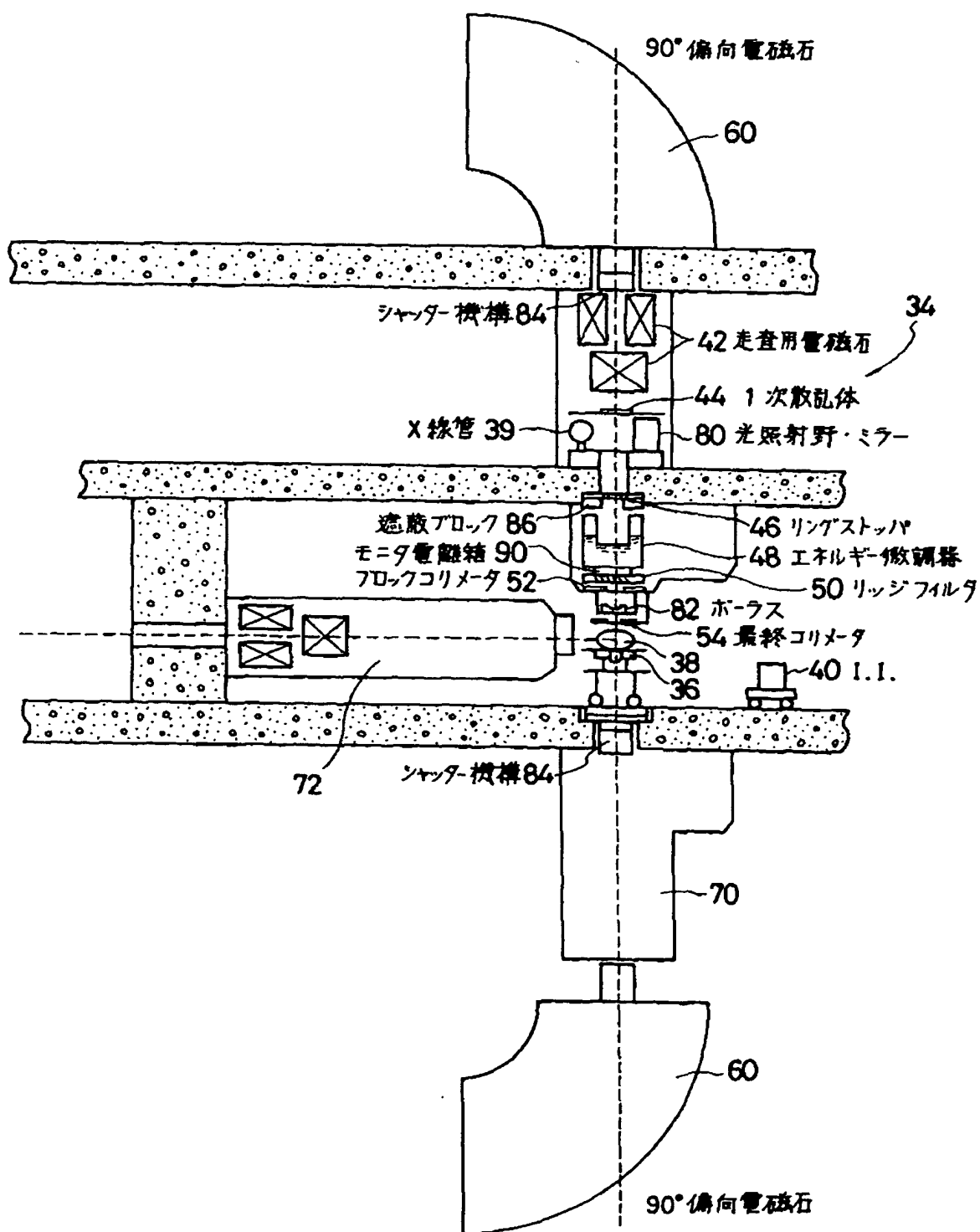
[ Drawing 1 ]



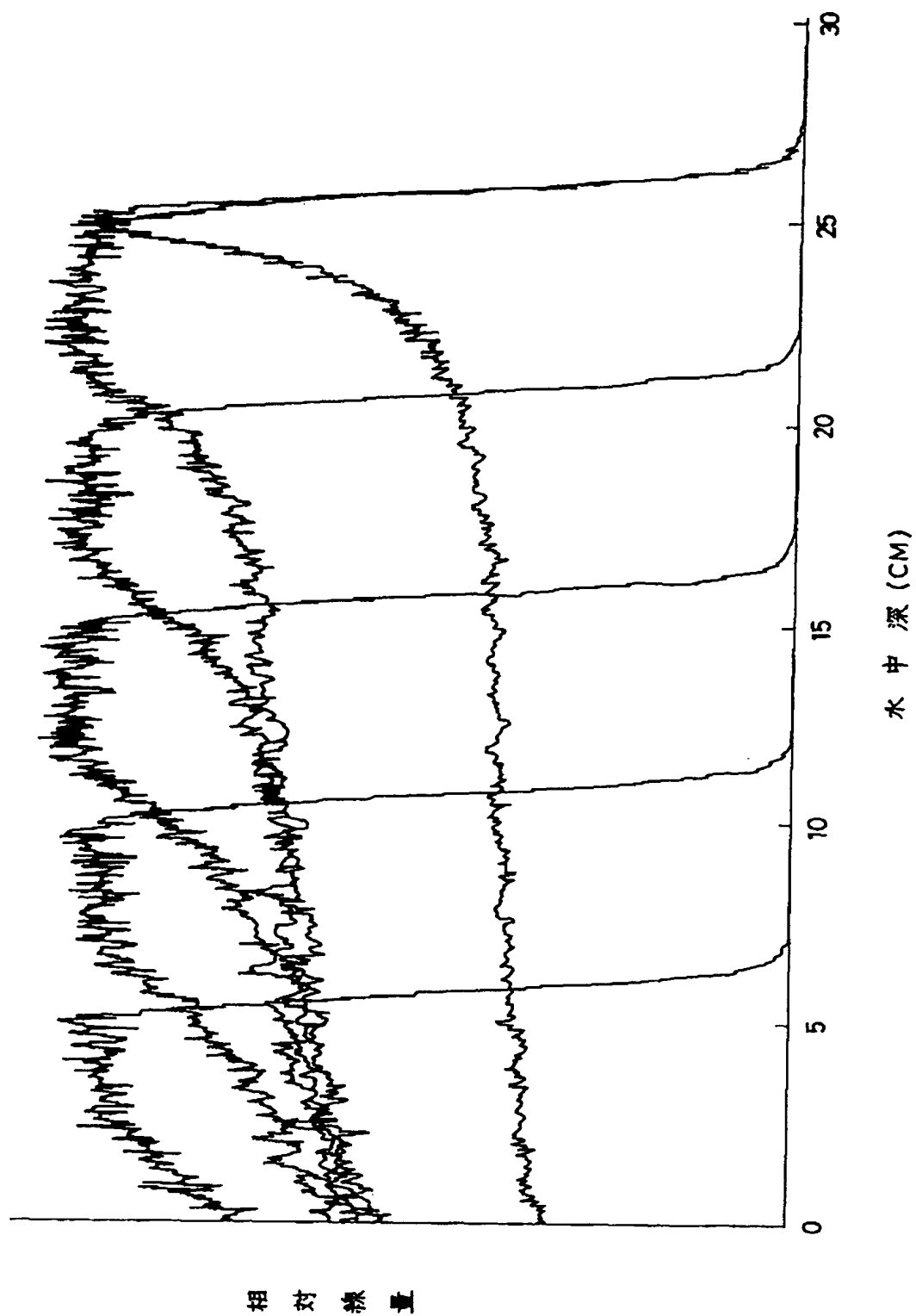
[ Drawing 2 ]



[ Drawing 3 ]



[ Drawing 4 ]



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最終頁に続く

(54)【発明の名称】 陽子線を用いた治療装置

1

【特許請求の範囲】

【請求項1】 個々の治療に必要なエネルギー、強度及び準定常的もしくはパルス状の時間構造を有する陽子線を生成する陽子線加速手段と、  
前記加速された陽子を輸送する輸送手段と、  
前記加速された陽子線を複数の方向に振り分ける振り分け手段と、  
前記複数の方向に振り分けられた陽子線を所定の治療室に導く手段と、  
前記治療室に固定して設けられ、前記治療室に導かれた陽子線を制御して、垂直上下方向または水平方向より前記陽子線を所定の部位に照射する照射制御手段とを具備し、  
前記照射制御手段が、  
前記陽子線を大照射野に拡大する散乱手段と、

2

散乱手段に対して独立に設けられ、前記所定の部位の最大深に合致する体内飛程をもつエネルギーに前記陽子線を調整するエネルギー減速手段と、  
前記部位に最大厚に合致する幅に、前記陽子線の線量ピーク幅を拡げる3次元的照射野形成手段であって、前記部位の形状に一致するように形状が調節可能で、かつ前記部位からの距離が異なる一対のコリメータを具備する3次元的照射野形成手段と、  
陽子線の前記部位に与える所要線量を監視するためのモニタ手段と、  
前記モニタ手段のモニタ値を積算し、その積算値がプリセット値に達すると照射停止信号を発生して、前記陽子線の線量制御を行う制御手段と、  
を具備することを特徴とする陽子線を用いた治療装置。  
【請求項2】 前記陽子線加速手段が、

陽子または負水素イオン生成するイオン源と、  
前記陽子または負水素イオンを予備加速する予備加速手段と、  
前記予備加速された陽子または水素を所要のエネルギーまで加速する主加速手段と、  
を有することを特徴とする請求項1に記載の装置。

【発明の詳細な説明】

(産業上の利用分野)

本発明は、陽子線を用いた治療装置に関し、陽子線を、例えば癌病巣に正確に一致させて大線量を集中させる陽子線治療装置に関する。特に、陽子線エネルギー減速を散乱とを同時に行い、また、線量ピーク幅を拡大する金属製フィルタを散乱に寄与せしめて、適切な形状の照射野を形成させる機能を有機的に結合させたシステムである。

(従来技術)

放射線による癌の治療には、X線、ガンマ線および電子線が使用されており、また最近では中性子線も導入されてきた。これらは線形加速器やベータトロンなどの小形電子加速器により発生する電子線やX線を照射するシステムであり、多数病院に設置されてきた。またガンマ線を用いたものの大部分は、コバルト60線源を格納する遠隔照射治療装置と各種の放射性核種を使用する小線源照射治療装置であり、普及している。これらの放射線治療装置は以下のような利点を有している。

(a) 手術にて摘出不能な癌症例の治療が可能である。

(b) 化学療法や温熱療法との併用で効果を高めることが可能である。

(c) 治療に成功すれば、組織の欠損や機能障害が軽減であるので患者の社会復帰が容易である。

(発明が解決しようとする課題)

上述したような従来の放射線治療装置では、電子線を除けば、体内での到達飛程の概念があてはまらず、ほぼ指数的に減弱する。また電子線においてもその統計的変や散乱が大きいため体内飛程は明瞭ではない。

よって、これらの従来の放射線の照射野形成においては、3次元照射野の形成制御が困難であり、いわゆる原体照射野法によって近似的に病巣への線量集中が画られてきた。

しかし、一般に癌病巣の形状は不定形かつ複雑であり、癌病巣はしばしば重要臓器内に、またはそれらに近接した位置に存在する。よって従来の放射線では正常組織に障害を与えずに癌病巣全体に十分に治療線量を与えることは困難であり、このことが放射線治療後の再発を招くという欠点があった。

本発明の目的は、周辺臓器など正常組織に与える線量を可及的に軽減し、不定形な例例えば癌病巣に十分に大きな線量を選択的に集中するために、陽子線の体内飛程を癌病巣最大深に一致させ、陽子線線量ピーク幅を病巣厚に一致させ、また、収束、輸送された陽子線束を拡大し

病巣全体を一様線量強度で蔽い、病巣線量を積算表示して、所要の予定線量にて照射停止を行わせる信号を発生し、しかもこのような制御を自動化して、陽子線による癌治療を容易に行える陽子線を用いた治療装置を提供することにある。

(課題を解決するための手段)

本発明の陽子線を用いた治療装置は、個々の治療に必要なエネルギー、強度及び準定常的もしくはパルス状の時間構造を有する陽子線を生成する陽子線加速手段と、前記加速された陽子を輸送する輸送手段と、前記加速された陽子線を複数の方向に振り分ける振り分け手段と、前記複数の方向に振り分けられた陽子線を所定の治療室に導く手段と、前記治療室に固定して設けられ、前記治療室に導かれた陽子線を制御して、垂直上下方向または水平方向より前記陽子線を所定の部位に照射する照射制御手段とを具備し、

前記照射制御手段が、

前記陽子線を大照射野に拡大する散乱手段と、散乱手段に対して独立に設けられ、前記所定の部位の最大深に合致する体内飛程をもつエネルギーに前記陽子線を調整するエネルギー減速手段と、前記部位に最大厚に合致する幅に、前記陽子線の線量ピーク幅を広げる3次元照射野形成手段であって、前記部位の形状に一致するように形状が調節可能で、かつ前記部位からの距離が異なる一対のコリメータを具備する3次元照射野形成手段と、陽子線の前記部位に与える所要線量を監視するためのモニタ手段と、

前記モニタ手段のモニタ値を積算し、その積算値がプリセット値に達すると照射停止信号を発生して、前記陽子線の線量制御を行う制御手段と、を具備することを特徴とする。

ところで、前記陽子線加速手段は、陽子または負水素イオンを生成するイオン源と、

前記陽子または負水素イオンを予備加速する予備加速手段と、

前記予備加速された陽子または水素を所要のエネルギーまで加速する主加速手段と、

を有することが好ましい。

本発明の装置を以下により詳しく説明する。本発明の装置は陽子加速器とビーム輸送系を具備する。陽子加速器とビーム輸送系は、水素分子より陽子または負水素イオンを生成させるイオン源、予備加速を行う入射器へ入射するための加速を行う前段加速部、入射器、入射器により予備加速された陽子線を主加速器に導く中エネルギービーム輸送系、がん治療に必要とされるエネルギーに陽子を加速する主加速器、陽子線を治療室に導く振り分け電磁石を含むビーム輸送系及びこれらの機器の制御部よ

り構成される。

入射器には、タンデム静電加速器または直線加速器を使用し、タンデム静電加速器には負水素イオンを、直線加速器には陽子または負水素イオンを入射する。タンデム静電加速器と陽子を入射する直線加速器は、陽子を予備加速して主加速器に入射し、負水素イオンを入射する直線加速器は負水素イオンを予備加速して荷電変換方式により主加速器に入射する。

主加速器はシンクロトロンで、入射された陽子を予備加速のエネルギーから病巣の位置と形状に対応したエネルギーまで高周波加速を行った後、陽子を主加速器からビーム輸送系に取り出す。

陽子ビームの取り出しに関しては、共鳴を利用してある時間内は準定常的にビームを取り出す遅い取り出しと、陽子が主加速器を一周する時間内に取り出す速い取り出しのいずれかを選択でき、いずれの方法により取り出された陽子ビームも同一の振り分け電磁石とビーム輸送系により、1または2以上の治療室の水平方向または垂直上下方向のいずれかの照射制御装置に導かれる。

加速器による陽子の加速は照射制御装置よりの信号により行い、加速器及びビーム輸送系の制御は安全確保のインターロックシステムと電算機により行う。

照射制御装置の原理的構成は、3次元照射野形成部と線量監視部から成る。

3次元照射野形成部は、エネルギー減速器と、エネルギー減速器上部に設けられた重金属板と、線量ピーク幅拡大フィルタとを有する。

エネルギー減速器は、2枚の楔状エネルギー吸収物質の重なり合う部分の厚さを変化させて所要のエネルギー吸収を行わせるものである。そして、遠隔的に1mm以内の精度で1分以内に所要の厚さに制御可能である。

収束ビームの拡大のために、光照射ミラー上部に重金属板の一次散乱体が装着され、その下方のリングストップと共に散乱機能を強化する。

線量ピーク幅拡大フィルタは、厚さに傾斜があるエネルギー吸収金属体であり、入射する鋭い線量ピーク部エネルギーを順次変化させて累積的に所要の幅の平坦な線量ピークとする。拡大幅1cmより15cmまで1cmステップで15組を用意し、これを4×4の方形に16枠をもつ移動台に装置し、遠隔的に選択する。なおそのうち1枠はblankとし、もとの線量ピークによる照射を可能とする。

線量監視部は、主、副一對の透過形平行平板電極をもつモニタ電離箱と、その出力電流の増幅器、積算表示器および線量プリセット器を有する。線量監視部は積算値が予定線量に達すると照射停止信号を発生し、陽子線照射を停止させるもので、操作・制御は電算機によって行うようにしたものである。

(作 用)

上記のように構成した本発明による陽子線を用いた治療装置によれば、陽子を加速して患者の病巣部位を照射で

きる。陽子線は体内に入射しても従来のX線、ガンマ線のように指数関数的にエネルギーが減少せず、所定の深さに線量ピークを有する線量分布を得ることが可能である。また、その線量分布を容易に調整可能であり、陽子線の飛程調整ができる。

従って、癌のように不定形でかつ複雑な形状であっても、陽子線の線量分布を調整することにより、所定の部位に照射可能である。そのため、正常な組織を障害を与えずに、治療することができる。

また、本発明の照射制御手段の具体的構成によれば、照射制御手段を治療室内に垂直上方向、垂直下方向、水平方向に固定的に設置している。このようにすると、陽子線の線量分布を変更するための種々の部材の調整が容易となり、この容易性のために、安全で適切な治療を実現できる。

このように本発明の照射制御手段によると、周辺臓器など正常組織に与える線量を可及的に軽減できる。また、不定形な例えば癌病巣に十分に大きな線量を選択的に集中するために、陽子線の体内飛程を癌病巣最大深に一致させ、陽子線線量ピーク幅を病巣厚に一致させ、また、収束、輸送された陽子線束を拡大し病巣全体を一樣線量強度で蔽うことが可能となる。更に、病巣線量を積算表示して、所要の予定線量にて照射停止を行わせる信号を発生するので、陽子線による癌治療を容易に行える。しかも、このような制御を自動化できる。

(実施例)

以下図面を参照して、本発明の陽子線照射装置の一実施例を説明する。

陽子加速器10、ビーム輸送系12、中エネルギービーム輸送系16の構成を第1図と第2図に示す。第2図は、第1図のビーム輸送系12のII-II方向から見た図である。陽子加速器10は六角形のシンクロトロンからなり、高周波加速部14を有している。シンクロトロンを六角形にすると、例えば4角形のものに比べて高性能の強集束型の設計が容易となり、且つ直線部が増えることにより多様なビームの取り出しが可能となる。ビーム輸送系12は、垂直上方向ビーム輸送系18、垂直下方向ビーム輸送系20と水平方向ビーム輸送系28とを具備している。

陽子を深部の病巣に到達させて治療を行うには、所要のビーム強度の陽子を所要のエネルギーまで加速しなければならない。例えば体内の32cmの深さに陽子を到達させるには、230MeVのエネルギーが必要となる。このようなエネルギーまで陽子を加速する本実施例に於ける手順を以下に説明する。

まず水素分子のイオン源から負水素イオンを生成させ、生成した負水素イオンを静電的に50keVまで加速し、予備加速を行うために入射器22に入射する。入射器22としてターミナル電圧2.5MVタンデム静電加速器を使用する。タンデム静電加速器を使用すると、エネルギー幅を低減できるメリットがある。負水素イオンは2.5MeVまで

加速されて、ターミナルで炭素薄膜により陽子に変換され、5MeVまで加速される。陽子の中エネルギービーム輸送系16により陽子加速器（主加速器）10に導かれる。主加速器10は超周期6の強集束型シンクロトロンで、その主要パラメーターを第1表に示す。陽子は一周約35mの軌道上を周回し、高周波加速部を通過する毎に加速され、約0.5秒の後に230MeVに達する。所要のエネルギーに達した陽子は、シンクロトロン10から取り出されてビーム輸送系12により治療室に導かれる。

陽子線のエネルギーは、病巣の深さに対応したものでなければならない。シンクロトロン10では加速の途中で任意のエネルギーでの取り出しが可能であるけれども、第一段階としては、エネルギーの切り替えの確実性と迅速性を考慮して、陽子線のエネルギーを120MeV、180MeV、230MeVの3段階とする。これが達成された後に任意のエネルギーでの取り出しが行なわれる。

一般にシンクロトロン10により、設計エネルギーを達成することは、現在の技術で確実となったが、ビーム強度の目標である20ナノアンペア（nA）を達成するには設計段階に於ける慎重な配慮と完成後の入念な調整が必要である。ビーム損失の多くは、シンクロトロン10への入射時、シンクロトロン10に於ける加速開始時、及びシンクロトロン10からの陽子の取り出しの際に起こる。入射器22のビーム強度があまり高くないので、シンクロトロン10の陽子の多数回入射を行ってシンクロトロン10のビーム強度を確保する。

なお入射器22として、負水素イオンを入射する8MeV以上の直線加速器を使用すれば、炭素薄膜による負水素イオンの陽子への変換を利用して、高効率でビーム強度制御の容易なシンクロトロン10への陽子入射ができる。

加速開始時のビーム損失は軌道補正磁石を予め準備して、これらを含めたシンクロトロン10の調整により対応する。シンクロトロン10からの取り出しに於けるビーム損失は、残留放射能の増加をもたらす、最も注意を要するものである。

ビーム取り出しの方式は、取り出し効率の高い半整数共鳴による遅い取り出しと、立ち上がりの速いキッカーによる速い取り出しのいずれかが選択できる。従って、遅い取り出しによりビーム走査による照射野形成も可能となる。

速いビーム取り出し効率は理論上100%が可能となり、超音波による体内に於ける陽子線の到達位置の計測を可能とすると共に、病巣器官の運動に同期して陽子加速を開始するかまたは予め加速した陽子ビームをシンクロトロン10に蓄積し、病巣器官の運動に同期して陽子ビームを取り出すことにより、正常組織の被ばく線量を低減した照射が可能となる。

加速器による陽子ビームの加速は、照射制御装置に設けられたモニタ電離箱（第3図の参照符号86）よりの信号により行う。遅い取り出しによる陽子ビームも、速い取

り出しによる陽子ビームも、同一のビーム輸送系12に取り出される。2治療室のうち、第1治療室24には垂直上下方向ビーム輸送系18、20と水平方向ビーム輸送系28、他の第2治療室26には垂直上下方向ビーム輸送系18、20から陽子ビームが供給される。垂直上下方向と水平方向の選択は振り分け電磁石30による。

ビーム輸送系12に於いては、所要の照射制御装置に陽子ビームを導くに要する電磁石（例えば第3図の90度偏向電磁石）以外の電磁石（例えば第1図の参照符号62、64で示される電磁石）の電源は安全確保の目的で断とする。この手順の条件は他の一般的条件と共に全システムの運転制御盤（図示せず）に格納されたインターロックシステムに組み込まれている。加速器10およびビーム輸送系12の運転条件の設定は前記運転制御盤に設けられた電算機により行う。

照射制御装置34の具体的な詳細構成を第3図に示す。図示の照射制御装置34は、第一治療室24に上下垂直および水平の3組の照射制御装置を設置した場合において、垂直上方向ビーム輸送系18からのビームを制御する上垂直の装置についての詳細な構成を示した。垂直下方向ビーム輸送系20のビームと水平方向ビーム輸送系28のビームと水平方向ビーム輸送系28のビームを制御する他の2組についても同様の構成となる。この他の2組は参照符号70、72により示されている。

各照射制御装置の中心軸に病巣を一致させるように、中央の治療台36上に患者38を固定する。その位置の確認は同軸上にX線管39およびイメージインテンシファイア（I. I.）40を移動させて行う。

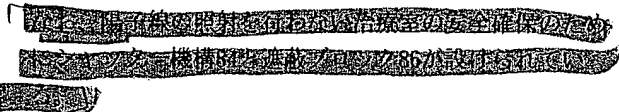
陽子線の照射野形成は、細束陽子線を走査用電磁石42で走査し、また、一次散乱体44により拡大し、リングストップ46にて、照射位置にほぼ均一強度の20×20cm以上の分布を形成することによりなされる。患者表面の照射野形成のビームの広がり確認は光照射野ミラー80によりなされる。

ビーム軸方向の飛程調整は、エネルギー微調器48によって所要の体内飛程に対応するエネルギーに減弱させ、線量ピーク幅が病巣厚に合致するようにリッジフィルタ50を選択して、その幅を拡大する。また、患者体表面および病巣の形状、体内の不均値病巣の深度に対応させて陽子線のエネルギー調整を行うためにボラス82が設けられている。ボラス82の厚みは各位置によって変化していて、その各位置を介して陽子線を通過させることにより、陽子線のエネルギーを吸収する。

病巣形状に一致するようにブロックコリメータ52の形状および最終コリメータ54の形状を調整する。

リッジフィルタ50とエネルギー微調器48との間にはモニタ電離箱90が設けられている。このモニタ電離箱90は、線量監視部の一部として機能し、その出力電流に対応した量の積算値が予定線量に対応したプリセット値を越えようと、照射停止信号が発生され、陽子線照射が停止され

る。これらの制御は電算機（図示せず）によりなされる。



また、この照射装置に設けられた上記各エレメントの配置状態、条件等は患者38の状態によって調整される。手動によってもこの調整は可能であるが、患者のデータに基づき電算機により自動的に調整する方が好ましい。

このような照射装置によれば、上下垂直および水平の3組の照射制御装置は固定されているので、操作が簡単であり、確実な治療ができると共に、メンテナンスが容易である。

また、走査用電磁石42、一次散乱体44、リングストップ46等の各エレメントが照射装置にほぼ固定的に組み込まれているので、調整が簡単であり、装置の安全性が高く、従って正確な治療が達成される。

第4図は、飛程が水中約25cmに鋭いピークを有する陽子線線量分布と、その鋭い線量ピークの幅を拡大し、飛程を調整した例を示す。このような飛程調整によっても、拡大線量ピークの形状および縦軸の線量強度が、極端にエネルギーを減弱した場合をのぞけば、ほぼ一定であった。

（発明の効果）

以上の説明から明らかなように、本発明によれば患者の病巣に合致して、陽子線の線量分布形状を調整することが可能である。この装置による病巣の陽子線線量率は毎分2-3Gyであり、通常の1回の照射時間は1分以内であるので、治療の実施は容易であり、患者の苦痛もない。

また、安全確実な治療を達成することができる。

第一表 230MeV陽子シンクロトロン主要パラメータ  
シンクロトロン格子

全周長	34.939m
平均直径	11.121m
超周期	6
構造	DOFB
直線部長さ	3m
偏向電磁石曲率半径	1.55m
偏向電磁石長さ	1.623m
入射ビーム	
エネルギー	5MeV
$\beta = v/c$	0.102826
運動量	0.323536Tm
規格化emittance（水平）（実効10回入射）	$30\pi\text{ mm. mrad}$
規格化emittance（垂直）磁場	1.5 $\pi\text{ mm. mrad}$
偏向磁場（5MeV）	0.208733T

(120MeV)	1.053394T
(230MeV)	1.497955T
立ち上がり	2.6T/sec
偏向電磁石偏向角	60度
ギャップ	6.5cm
磁極幅	30cm
端縁角	30度
Q磁石aperture	11.6cm
長さ	20cm
Q磁場（F）	5.948308T/m
（D）	1.141559T/m
軌道	
$\nu$ （水平）	1.8
$\nu$ （垂直）	1.85
$\beta$ （水平）	1.8357-6.4391
直線部中央	2.8271
$\beta$ （垂直）	1.6838-6.9554
直線部中央	2.3254
分散（最大）	2.6
（直線部中央）	2.1
$\gamma$ （transition）	1.560583
入射時最大ビーム幅（水平）	
betatron	$\pm 4.3\text{ cm}$
分散	$\pm 0.8\text{ cm}$
COD	$\pm 3\text{ cm}$
合計	$\pm 8.1\text{ cm}$
入射時最大ビーム幅（垂直）	
betatron	$\pm 1.0\text{ cm}$
COD	$\pm 1.7\text{ cm}$
合計	$\pm 2.7\text{ cm}$
加速高周波	
周波数（5-230MeV）	0.882293-5.112299MHz
安定位相（5-230MeV）	20-30度
電圧（5-230MeV）	450-300V
周期	
速い（遅い）取り出し	1（0.5）Hz以上

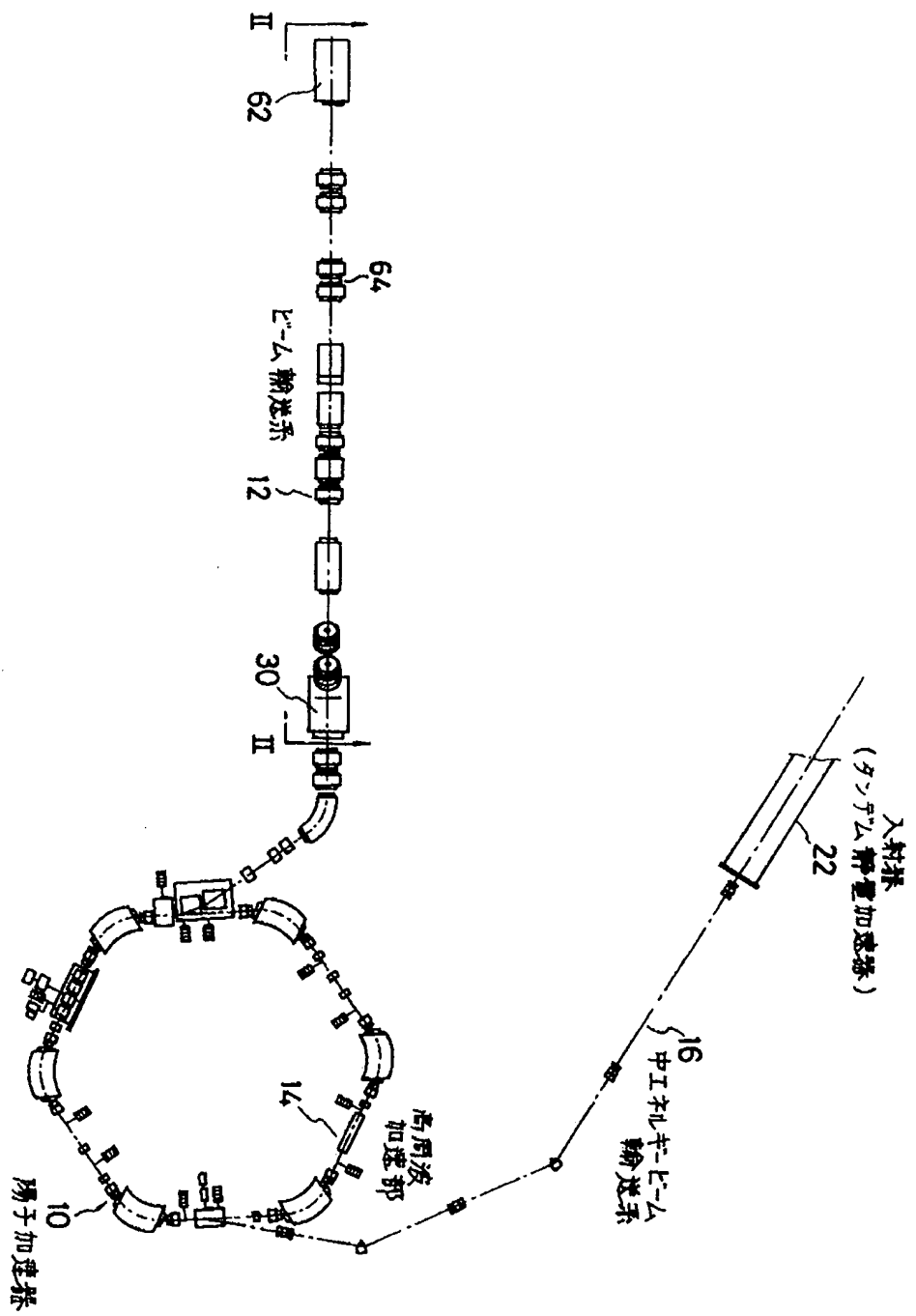
【図面の簡単な説明】

第1図は、本発明に係る陽子線を用いた治療装置の平面図、

第2図は、第1図の装置のうち振り分け電磁石より下流のビーム輸送系のII-II線から見た図、

第3図は、本発明の治療装置に用いられている照射制御装置の垂直上方部分の構成図、

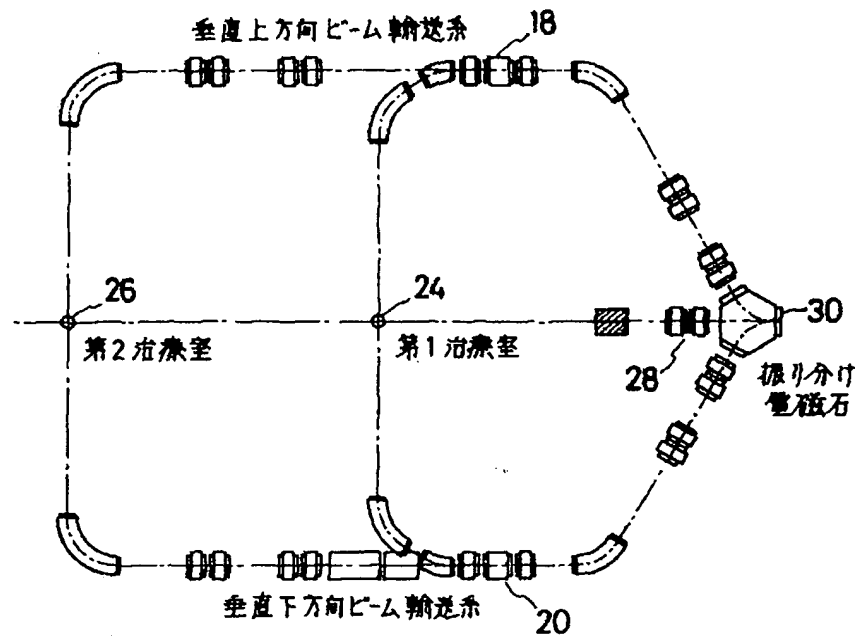
第4図は、本装置により照射された水中約25cmに鋭い線量ピークを示す加速陽子線と、各飛程に減速されかつ線量ピーク幅を拡大された陽子線との水中における相対線量分布を示す図である。



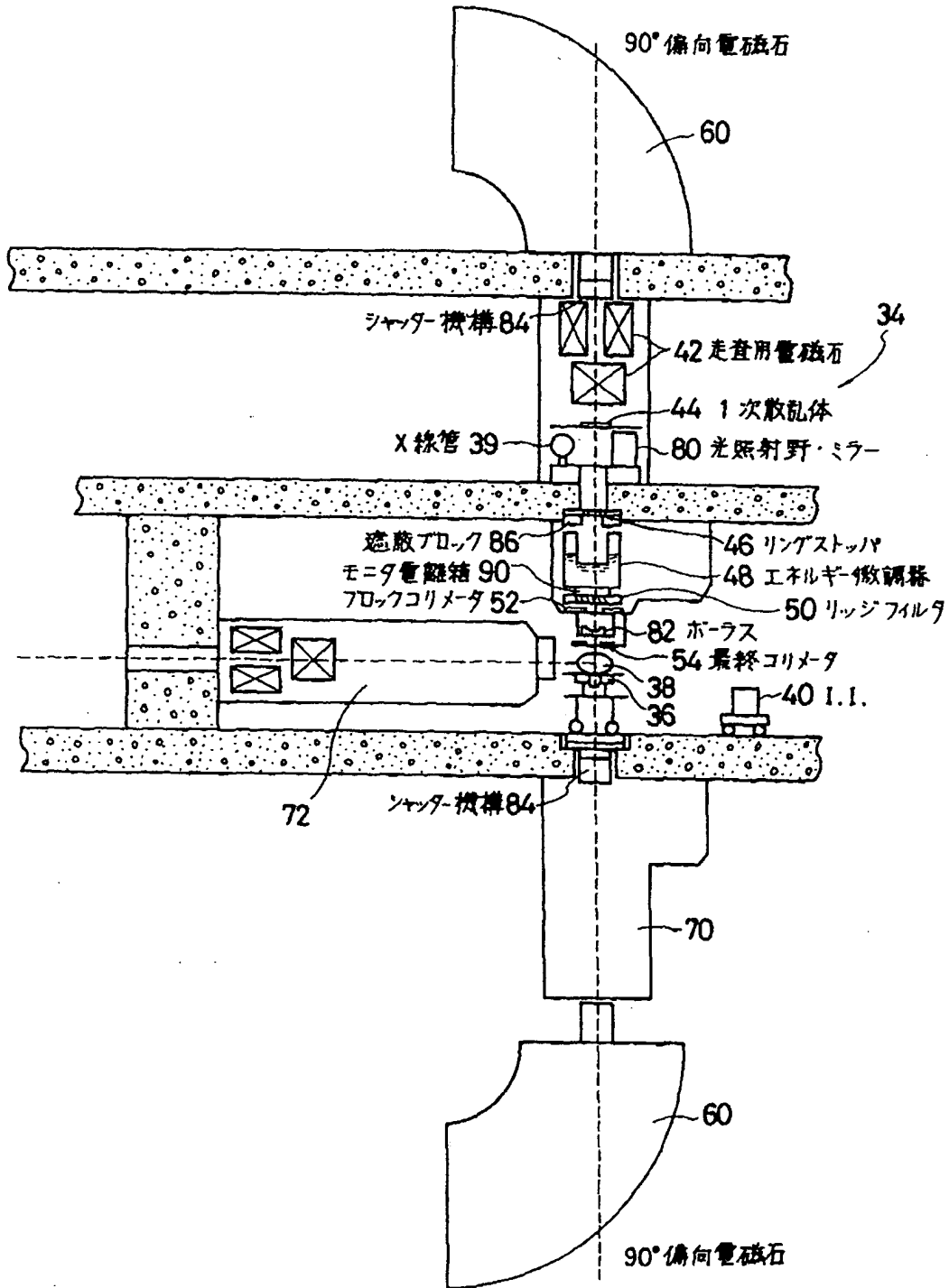
【第1図】

(6)

【第2図】

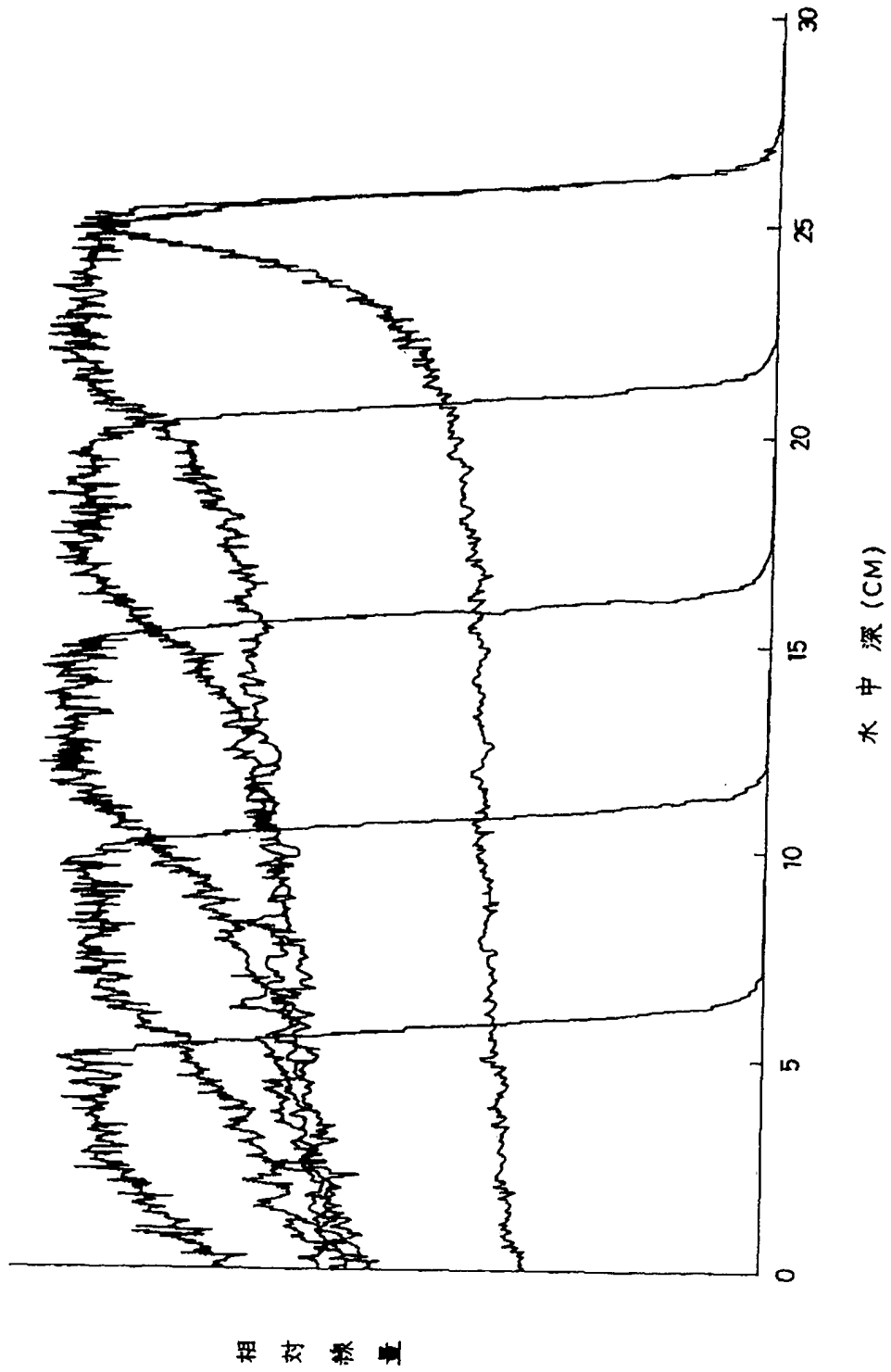


【第3図】





【第4図】



フロントページの続き

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